APPENDIX E

SUPPLEMENTARY TIEBACK INFORMATION

The following were copied from the Federal Highway Administration Report No. FHWA-RD-75-128, "LATERAL SUPPORT SYSTEMS AND UNDERPINNING"; Vol. I. Design and Construction, pages 199 - 227

The following was copied from Federal Highway Administration Report No. FHWA-RD-75-130, "LATERAL SUPPORT SYSTEMS AND UNDERPINNING"; Vol. III. Construction Methods, pages 212 - 213

TIEBACK TYPES BY PRESSURE

Summary of tieback types and applicable soil types.

Method	Diameter(inches) Shaft Type	Bell Type	Gravity Concrete	Grout Pressure (psi) (1)	Suitable Soils for Anchorage	Load Transfer Mechanism
1. LOW PRESSURE						
Straight Shaft Friction (Solid stem auger)	12-24" (30 - 60cm)	NA	A	NA	Very stiff to hard clays Dense cohesive sands	Friction
Straight Shaft Friction (Hollow stem auger)	6-18" (15 - 45cm) (12-14" most common)	NA	NA	30 - 150 (200 - 1035 kN/m2)	Very stiff to har clays Dense cohesive sands Loose to dense sands	Friction
Underreamed Single Bell at Bottom	12-18" (30 - 45cm)	30-42" (75 - 105cm)	A	NA	Very stiff to hard cohesive soils Dense cohesive sands Soft rock	Friction and bearing
Underreamed Multi-Bell	4-8" (10- 20cm)	8-24" (20- 60cm)	A	NA	Very stiff to hard cohesive soils Dense cohesive sands Soft rock	Friction and bearing
2. HIGH PRESSURE-SMALL DIAMETER						
Non-regroutable (2)	3-8" (7.5 - 20cm)	NA	NA	150 (1035 kN/m2)	Hard clays Sands Sand gravel form-ations Glacial till or hardpan	Friction or friction and bearing in permeable soils
Regroutable (3)	3-8" (7.5 - 20cm)	NA	NA	200-500 (1380 - 3450 kN/m2)	Same as for non-regroutable anchors plus: a) stiff to very stiff clay b) varied and difficult soils	Friction and bearing

(1) Grout pressures are typical
(2) Friction from compacted zone having locked in stress. Mass penetration of grout in highly pervious sand/gravel forms "bulb anchor".
(3) Local penetration of grout will form bulbs which act in bearing or increase effective anchor diameter.

A - applicable
NA - not applicable

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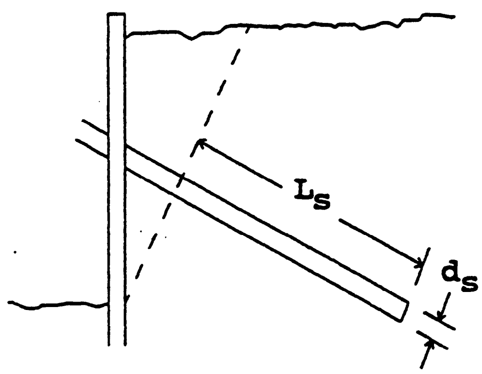
ANCHOR CAPACITY FORMULAS - LARGE DIAMETER

Large diameter anchors can be either straight shafted, single-belled, or multi-belled. These anchors are most commonly used in stiff to hard cohesive soils that are capable of remaining open when unsupported: however, hollow flight augers can be used to install straight-shafted anchors in less competent soils.

The methods used to estimate the ultimate pullout capacity of large diameter anchors are largely based on the observed performance of anchors and are, therefore, empirical in nature. The following equations can be used to estimate anchor load capacity; fieldtesting of anchors is required to determine true anchor capacity.



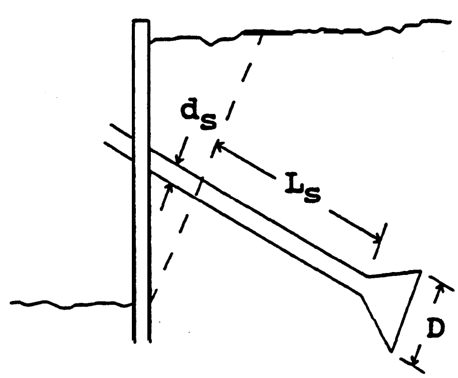
(a)
Friction Anchor

a. Straight-shafted Anchor

$$P_u = \alpha S_u \pi d_s L_s$$

where:

d_s = diameter of anchor shaft
L_s = length of anchor shaft
S_u = undrained shear strength of soil
α = Reduction factor in S_u due to disturbance, etc. α = 0.3 - 0.5 (Hanna, 1973a; Broms, 1968: Littlejohn, 1970a; Neely and Montague-Jones, 1974).



(b)
Belled Anchor

b. Belled Anchor

$$P_u = \alpha S_u \pi d_s L_s + \pi/4(D^2 - d_s^2) N_c S_u$$

(Littlejohn, 1970a)

where:

d_s, L_s, S_u and α are as before
D = diameter of anchor bell
N_c = bearing capacity factor = 9

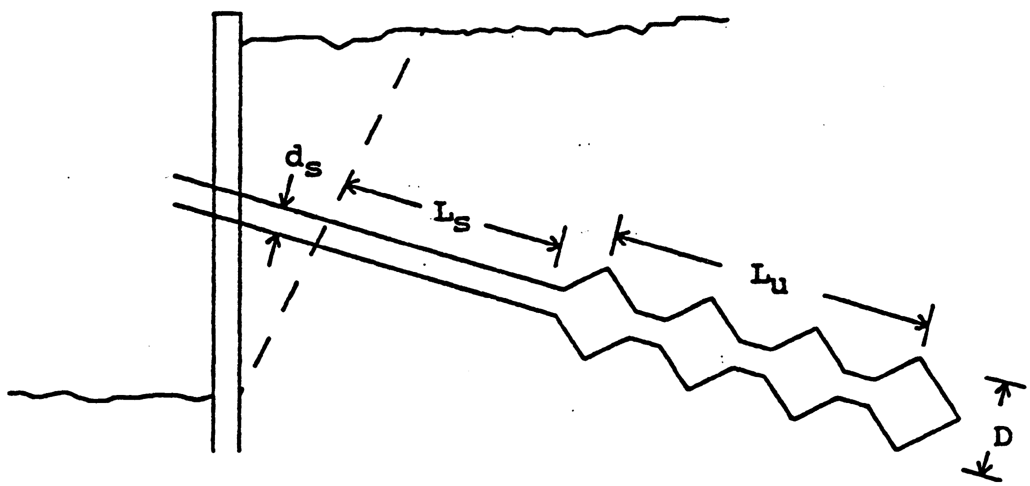
c. Multi-belled Anchor

$$P_u = \alpha S_u \pi d_s L_s + \pi/4(D^2 - d_s^2)N_c S_u + \beta S_u \pi D L_u$$

where:

d_s, L_s, S_u, α, N_c, D are as before
L_u = length of underreamed portion of anchor
β = reduction factor in S_u for soil between underream tips
= 0.75 - 1.0 (Littlejohn, 1970a; Bassett, 1970; Neely and Montague-Jones, 1974)

In order for failure to occur between the underream tips, the tips must be spaced at 1.5 - 2.0 times the belled diameter with the bell diameter equal to 2.0 to 3.0 times the shaft diameter.



(c)
Multi-belled Anchor

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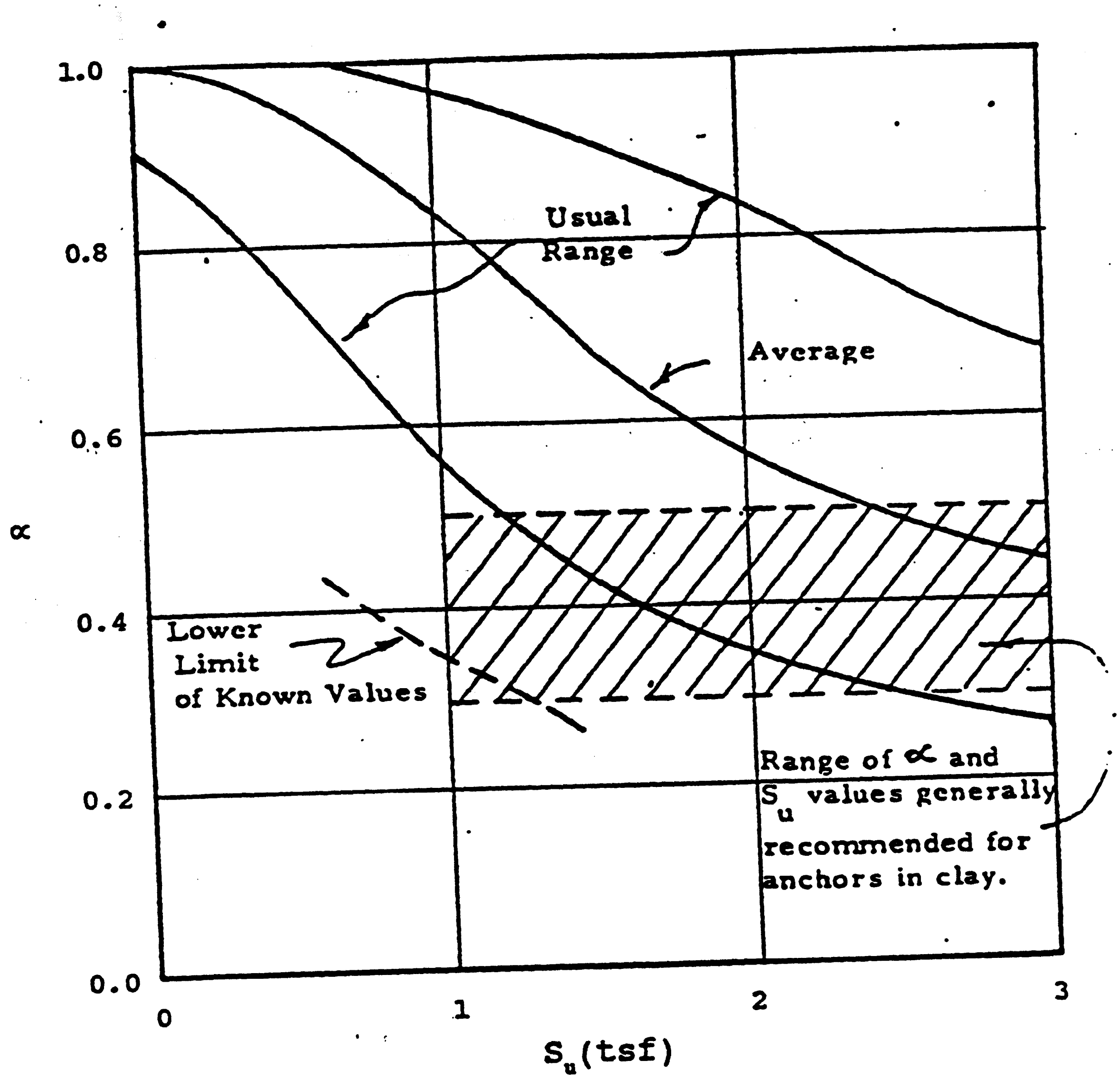
REDUCTION FACTORS FOR CLAY



From Peck, Hasnson & Thornburn (1974)

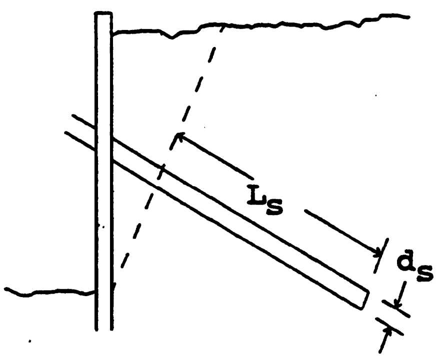
NOTE: 1 tsf = 95.8 kN/m^2
Reduction factor in S_u from observed capacity of friction piles.

ANCHOR CAPACITY FORMULAS - SMALL DIAMETER

Small diameter anchors are generally installed in granular soilswith grouting taking place under high pressure (usually greater than 150 psi (1035 kN/m^2). The anchor capacity will depend upon the soil type, grouting pressure, anchor length, and anchor diameter. The way in which these factors combine to determine anchor loads is not clear; therefore, the load predicting techniques are often quite crude. The theoretical relationships in combination with the empirical data can be used to estimate ultimate anchor load.

a. Theoretical Relationships

1. No grout penetration in anchor zones



(a)
Friction Anchor
(No Grout Penetration)

$$p_U = p_i \pi d_s L_s \tan \phi_e$$

where:

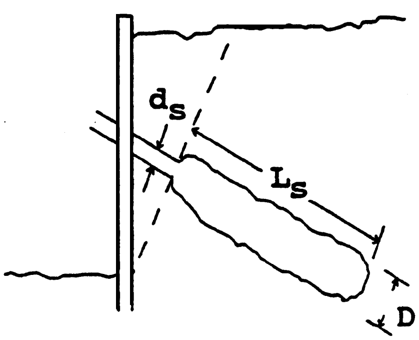
d_s = diameter of anchor shaft
L_S = length of anchor shaft
ϕ_e = effective friction angle between soil and grout
p_i = grout pressure

or $p_U = L_s n_1 \tan \phi_e$ (Littlejohn, 1970a)

where:

n_1 = 8.7 - 11.1 k/ft (127 - 162 kN/m)

2. Grout penetration in anchor zone (very pervious soils)



(b)
Bulb Anchor
(Grout Penetration)

$$P_u = A\bar{\sigma}_v \pi D L_s \tan\phi_e + B\bar{\sigma}_{v@end} \pi/4 (D^2 - d_s{}^2)$$

(Littlejohn, 1970a)

where:

d_s, D, L_s, and ϕ_e are as before

$\bar{\sigma}_v$= average vertical effective stress at anchor entire anchor length

$\bar{\sigma}_{v@end}$ = vertical effective stress at anchor end closest to wall

A = (Contact pressure at anchor soil interface)/(effective vertical stress, $\bar{\sigma}_v$)

Littlejohn reports typical values of A ranging between 1 and 2

B = bearing capacity factor similar to N_q but smaller in magnitude. A value of B = N_q/(l.3 - 1.4) is recommended provided $\geq$ 25D; where h is the depth to anchor.

Since the values of D, A and B are difficult to predict, Littlejohn (197Oa) also suggests:

$$P_u = L_s n_2 \tan \phi_e$$

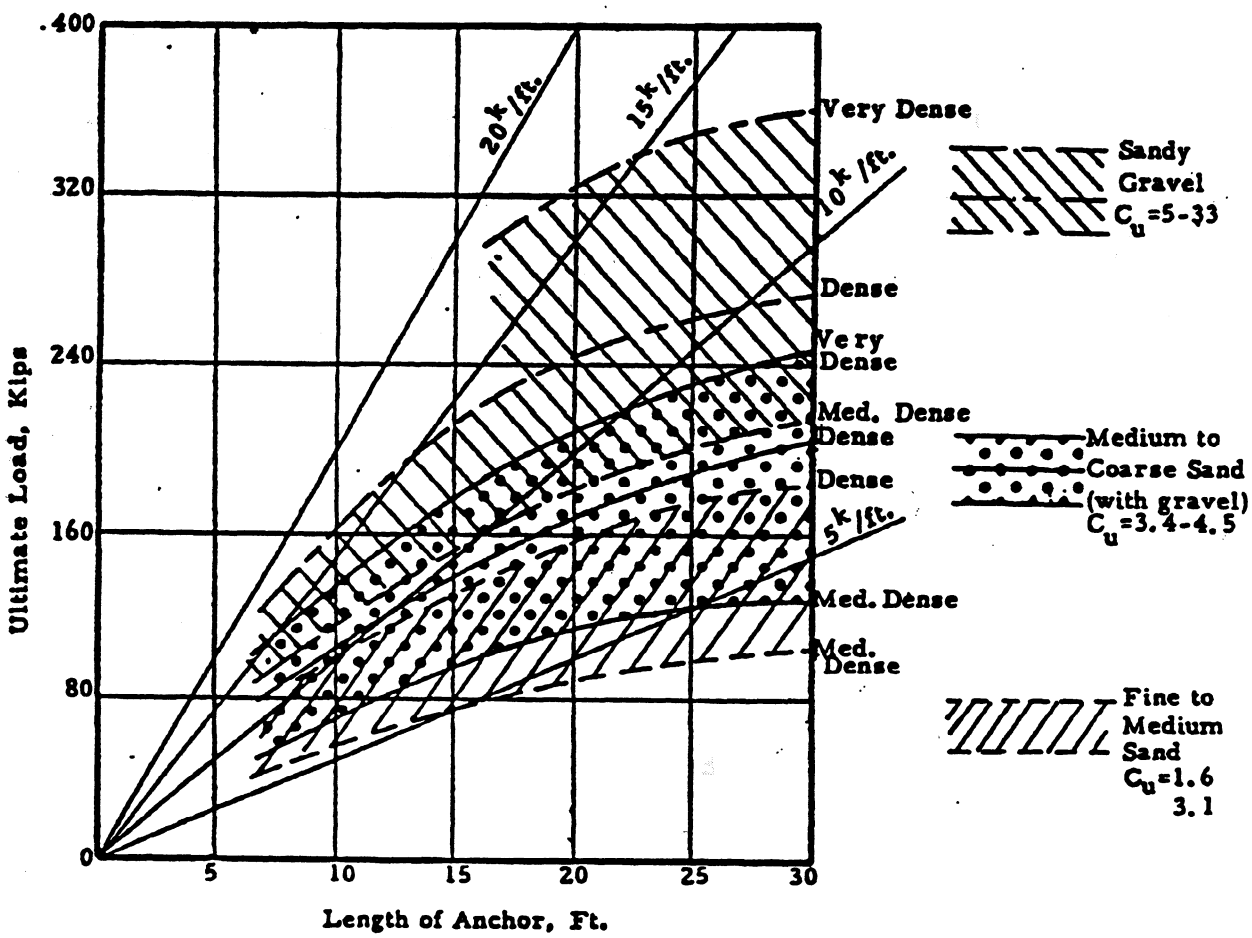
where:

n_2 = 26 - 40 kips/ft	or	(380 - 580 kN/m)
L_s = 3 - 12 ft	or	(0.9 - 3.7 m)
D = 15 - 24 inches	or	(400 - 610 m)
depth to anchor = 40 - 50 ft	or	(12.2 - 15.1 m)

b. Empirical Relationships

The figure on the following page presents an empirical plot of the load capacity of anchors founded in cohesionless soils. This figure was developedby Ostermayer (1974) and represents the range of anchor capacities that may develop in soils of varying densities and gradiations.

ANCHOR CAPACITIES IN COHESIONLESS SOILS



Note: 1 ft = 0.305 m
1 in = 2.54 cm
1 k/ft = 14.6 kN/m

Diameter of Anchor 4" - 6"
Depth of Overburden ≥ 13'

Load capacity of anchors in cohesionless soils showing effects of relative density, gradation, uniformity and anchor length.

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ANCHOR CAPACITY FORMULA - ROCK

Most rock anchors are straight-shafted friction anchors of 4 inches to 6 inches in diameter. In the past it has been assumed that the load is transmitted uniformly along the grout-rock interface, and most anchor design has been based upon this assumption. Littlejohn (1975) reports the results of studies performed by several authors that indicate that this assumption may not be valid. However, in the absence of more detailed information the establishedmethods should still be used. The designer should be aware of the potential problems of local debonding. Rigid field testing should establish anchor adequacy.

The equation used to estimate anchor capacity is:

$$P_u = \pi d_s L_s \delta_{skin}$$

where:

d_s = diameter of anchor shaft
L_s= length of anchor shaft
δ_{skin} = grout-rock bond strength

The values of skin friction δ_{skin}, for various rock types are summarized in the table on the following page.

In soft rock, it is also possible to form belled or multi-underreamed anchors. The equations governing the ultimate loads in these rocks are given in previous equations. In these cases, the cohesive strength of the rock becomes the controlling quantity.

BOND STRESS VALUES FOR ROCK TYPES

Typical values of bond stress for selected rock types.

Rock Type (Sound, Non-Decayed)	Ultimate Bond Stresses Between Rock and Anchor Plug (δ_{skin})
Granite & Basalt	250 - 800 psi
Limestone (competent)	300 - 400 psi
Dolomitic Limestone	200 - 300 psi
Soft Limestone	150 - 220 psi
Slates and Hard Shales	120 - 200 psi
Soft Shales	30 - l20 psi
Sandstones	120 - 250 psi
Chalk (variable properties)	30 - 150 psi
Marl (stiff, friable, fissured)	25 - 36 psi

1 psi = 6.90 kN/m^2

NOTE: It is not generally recommended that design bond stresses exceed 200 psi even in the most competent rocks.

Data is summary of results presented in:

1. Inland-Ryerson (1974 - ACI Ad Hoc Committee)
2. Littlejohn (1970)
3. Littlejohn (1970)

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ANCHOR CAPACITY FORMULA - GRAVEL PACKED ANCHORS

A gravel packed anchor is used on cohesive soils primarily to increase the value of the undrained shear strength coefficent, α. The original anchor hole is filled with angular gravel. A small closed-end casing is then driven into the hole displacing the gravel into the surrounding clay. Grout is then injected as the casing is withdrawn. The grout penetrates the gravel and increases the effective anchor diameter. The irregular surface also improves the strength along the grout-soil interface.

Littlejohn (1970a) proposes that the following equation be used for determining the ultimate load of a gravel packed anchor. There are terms for both frictional resistance and end bearing. A substantial increase in the value of the undrained shear strength coefficient is recommended, and the anchor diameter is larger.

$$P_u = \alpha S_u \pi D L_s + \pi/4 (D^2 - d_s^2) N_c S_u$$

where:

d_s, D, L_s, S_u are as before and $N_c = 9$
a = 0.6 - 0.75 = undrained shear strength coefficent